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ENHANCEMENT OF LIMBIC SEIZURES BY NOCTURNAL APPLICATION OF EXPERIMENTAL MAGNETIC FIELDS THAT SIMULATE THE MAGNITUDE AND MORPHOLOGY OF INCREASES IN GEOMAGNETIC ACTIVITY

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Over a 200 day period, chronic (limbic) epileptic rats were exposed intermittently, for either one or three nights (00 to 08 hr), once very approximately 10 days to experimental magnetic fields whose morphology (incremental changes in intensity over time) simulated geomagnetic activity. One of two intensities and two ripple frequencies (7 Hz, 45 Hz) was employed. The display of overt seizures following synchronized food presentation significantly increased by a factor 3.1 relative to controls when the fields had been activated for one or two but not three successive nights. The combined effects of the experimental field and ambient geomagnetic activity (>40 nT) explained approximately 12 to 15% of the variance in the daily incidence of seizures. Implications for the transient disinhibition of electrical lability within the limbic system following suppression of nocturnal melatonin are discussed.

Keywords: Limbic seizures, magnetic fields

Several correlational studies, involving yearly, monthly and daily analyses, have shown statistically significant associations between increases in the magnitude of global geomagnetic activity and the enhancement of behaviours that are associated with limbic epilepsy or epileptogenic phenomena (Keshavan, Gangadhar, Gautam, Ajit & Kapur, 1981; Rajaram and Mitra, 1981). They include sudden cardiac death (Persinger, 1995a), reports of bereavement hallucinations (Persinger, 1988) and vestibular experiences (Persinger & Richards, 1995). The effect sizes accommodate about 9% to 16% of the variance in these measures (equivalent to correlation coefficients between 0.30 to 0.40). Many of these effects are not intensity-dependent but exhibit a threshold effect or all-or-none occurrence when the global geomagnetic activity exceeds approximately 15 to 20 nanoTesla (nT).

Although a variety of research groups (Roberts, *et. al.*, 1992; Persinger & Makarec, 1993) have observed alterations in a continuum of behaviours that were inferred as indicators of changes in the threshold for electrical seizures, experiments designed to determine if specific magnetic fields could affect this continuum have involved: 1) field strengths that exceeded the magnitudes of geomagnetic variations by at least a factor of 100 to 1000, 2) symmetrical wave forms (quite unlike the natural signatures), 3) funda-

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mental frequencies that were several orders of magnitude higher than geomagnetic ranges (mHz), and 4) brief (30 min to 1 hr) exposure periods. In general the application of experimental magnetic fields have resulted in an inhibition of the display of behaviours correlated with limbic electrical seizures rather than their facilitation (Bureau & Persinger, 1995).

Two recent and relatively replicable experiments have offered a possible mechanism and procedure by which one might isolate the critical temporal and spatial parameters of daily geomagnetic activity that influence electrical lability within the limbic system. The first was the demonstration that a one hour exposure to experimentally controlled magnetic fields significantly lowers nocturnal melatonin if the fields are activated during the midscotophase (Lerchl, Honaka & Reiter, 1991; Yaga, Reiter, Manchester, Nieves, Sun & Chen, 1993). The second demonstration was the elicitation of spontaneous seizures in chronic epileptic rats following the presentation of either experimental magnetic fields (Michon, Persinger and Koren, 1996) or the natural enhancement of geomagnetic activity (Persinger, 1995b) during the local night. Because melatonin exhibits anticonvulsant effects upon hippocampal activity (Zeise & Semm, 1988), a reduction in the threshold for limbic seizures would be expected.

The overt display of limbic seizures, defined by spontaneous onset of rearing, rapid forepaw clonus and falling, is a common characteristic of rats in which chronic epilepsy had been induced several weeks previously by a single systemic injection of lithium and pilocarpine (Persinger, Bureau, Kostakos, Peredery and Falter, 1993). Synchronized delivery (same time of day each day of pellets of food) to groups of these chronically epileptic rats (even when they are not food deprived and food was available *ad libitum*), increased the overt display of spontaneous seizures within time frames that strongly implied enhanced release of CRF (corticotrophin releasing factor) because they could be attenuated by receptor antagonists for this neuropeptide. If there had been a sudden increase in global, daily geomagnetic activity (above 20 nT) during the previous midscotophase and a consequent increase in geomagnetic activity occurred at the time of the food stimulus, the proportion of overt seizures within 10 min increased by a factor of about 3 (Persinger, 1995b).

In most oscillating physical systems magnitude is confounded by frequency. As frequencies increase the magnitudes or strengths (given the same energy source), usually decrease. Contemporary theories suggest that the resonance frequency (Lerchl, Reiter, Howes, Nonaka & Stokkan, 1991) or Jacobson effects (1994) rather than the gross magnitude, particularly with phenomena that exhibit all-or-none patterns, is the more critical parameter. Resonance frequencies would be expected to ride or "ripple" upon fundamental carriers whose periods occur within the mHz range. Consequently the temporal-spatial configuration of the applied field would determine the "key" for this class of phenomena rather than the average intensity (strength of the "key") of the applied field.

To test this concept a field pattern was designed that attempted to simulate the characteristics of a sudden impulse or sudden storm commencement. According to Mayaud (Mayaud, 1975), these changes in geomagnetic intensity exhibit an average rise time of 4 min over a magnitude range of 10 to 50 nT. Even from the context of traditional physical models, this temporal structure in geomagnetic variation should be the optimal candidate to affect neuronal networks because it is a strong (mathematical) derivative. In fact the occurrence of these events during local night were significantly associated with incidences of sudden death in chronic (limbic) epileptic rats over a two year period (Persinger, 1995a).

METHOD

Subjects

Four male, Wistar albino rats obtained from Charles River (Quebec), approximately 80 days at the beginning of the experiment served as subjects.

Apparatus

There were four, identical 32 cm by 36 cm by 45 cm plastic cages. At any given time each of two of these cages was surrounded by one of two Helmholtz coils (30 ohms) connected in parallel to a custom built output for a Model EU 81A Heath-Schlumberger function generator. Light intensity during the day phase within each cage ranged between 700 and 800 lux (Gossen Panlux meter). The background 60 Hz magnetic fields within each of the cages, when the experimental fields were off was less than 10 nT (0.1 mG) as determined by a Metex M-3800 digital multimeter and sensor [Electric Field Measurement, W. Stockbridge, MA 01266]. When the experimental field was activated, the intensity increased in equal increments four times during the rising component of the field (1 min/increment), remained in plateau for 2 min and then decreased by the same four equal increments (30 sec/increment). The total time required for this synthetic "storm commencement" to be completed was 8 min.

Procedure

Each rat was injected s.c. first with 3 mEq/kg of lithium chloride and then 4 hr later with 30 mg/kg of pilocarpine. They were then individually restrained according to methods described earlier (Bureau and Persinger, 1993). Within 1 hr after the injection of this muscarinic agent (and after verification of overt seizures and myoclonus), each rat received 25 mg/kg of acepromazine in order to facilitate survival (Persinger, *et. al.*, 1993). After 5 days of recovery, these chronically epileptic rats were placed singly in one of the four plastic cages. For the remainder of the experiment, the temperature in the room was homeostatically controlled to remain between 19 and 21 deg C; the light:dark cycle was 12:12 with the local onset at 0800 hr.

On each day food was delivered between 1800 and 1930 hr to each cage separately. The amount of food delivered per day for each rat was determined by the weight consumed on average per week by an ad libitum reference group who were within 10 gm of the experimental rats and had arrived in the same shipment. The food was delivered carefully to each cage in order to minimize startle. During the next 10 min the rats were observed closely. The occurrence of an overt seizure, which was conspicuous and consisted of staring, rapid forelimb clonus (usually beginning with the left forepaw), rearing and falling (total duration about 30 sec, after which the rat returned to eating), was recorded for each rat. These events were extremely robust, exhibited an interobserver agreement of 100% and were not easily influenced by immediate environmental nuances. Corncob bedding of the cages was refreshed once per week during a period after the observation for that day (at which time the appropriate food was replaced).

During the first 100 days of the experiment two of the rats were maintained within the Helmholtz coils while the other two rats were maintained in the reference space immediately below and 30 cm from both coils; the condition of the pairs of rats were then reversed

for the second 100 days of the experiment. The primary design of the experiment involved two frequencies (7 Hz and 45 Hz) whose values were selected because of their similarity to the Schumann Resonance (Campbell, 1967) and to the approximate value of a burst-firing field (Richards, Persinger and Koren, 1993) that has been shown to affect the electrodynamic coherence of cerebral tissue (Silberstein, 1995). These ripple frequencies were generated by the square-wave mode of a Heath Schlumberger function generator and rode upon the step-increases and step-decreases of intensity of the synthetic "sudden impulse" or "sudden storm commencement".

The intensity for half of the exposures was attenuated by a factor of 10. The presentation times of the two conditions were randomly determined, before the experiment, for each of the two components of the experiment. For the 45 Hz field condition, the successive steps of intensity (from the 10 nT background) were 1200 nT, 2800 nT and 3800, 4800 nT for the high intensity condition and 120 nT, 280 nT and 380 nT and 480 nT for the low intensity condition. For the 7 Hz field condition the successive steps for the high intensity condition were 240 nT, 440 nT, 640 nT and 850 nT; these values for the low intensity condition were 24 nT, 44 nT, 64 nT and 85 nT.

The durations of exposure to the experimental magnetic fields (numbers of successive nights) were either 1 night or 3, successive nights. Consequently during the 100 day periods for each experiment there were 8 separate presentations of the field (2 frequencies by 2 intensities by 2 durations) about once every 1 to 3 weeks. The order of presentation for these parameters was randomly determined. For part I of the Experiment, the 8-min, sequence of step-changes in experimental field strengths occurred once per hour for every hour between midnight and 0800 occurred on either 1 or 3 successive nights while for part II of the Experiment, the 8 min step-changes increased and decreased continuously during the nightly 8-hr period. To extract the variability in the daily display of overt seizures due to the ambient geomagnetic activity, the daily A values from Fredricksburg (Virgina) were loaded.

An unplanned event occurred during the middle of part I of the experiment that was revealing and potentially relevant for all studies that pursue these phenomena. The power-racks required to operate operant chambers programmed for a DRL-6 sec schedule (minimum of one reward every 6 sec), had been moved against the wall adjacent to the four cages (without the experimenter's knowledge). Later measurements indicated that the cages were exposed to 1000 nT (10 mG), 60 Hz fields upon which were pulsed (not determinable) brief transients associated with the discharge of the magazines that delivered the food pellets. These unspecified field parameters were present for at least four hours per day before and during the daily presentation of the food stimulus over a 3 wk period.

The primary analysis involved multiple regression for the rats that were exposed to the experimental fields and for the rats exposed to the control condition, separately. The independent variables were the presence or absence of the experimental fields and the daily geomagnetic activity. Because previous studies had shown that these seizures are more frequent when A values from Fredricksburg exceeded 20 (40 nT), a digital variable (20 or above = 1; less than 20 = 0) was calculated. For the entire observation period specific tests were completed by using one-way analysis of variance and lagged variables to determine if the seizures occurred after the onset or the offset of the field or during the first or subsequent nights. Two-way analysis of variance was employed to determine if there were differential frequency and intensity effects upon the incidence of seizures. All analysis employed SPSS software on a Vax 4000 computer.

RESULTS

The means and standard deviations for the daily scores for seizures per day (range from 0 to 2) for the dyad of rats that were exposed to the experimental fields or to the control (reference) environment for part I and part II (conditions for pairs of rats reversed) are shown in Table 1. For part I, one-way analysis of variance indicated that there were significantly [$F(1,98) = 8.51$, $p < .01$; eta = 0.29] more overt seizures during the 10 min period following the food-stimulus presentation during the 100 day period for those days when any experimental field had been presented; there were no significant differences during these periods for the rats exposed in the control cages [$F(1,98) = 1.89$, $p > .05$]. For part II of the experiment, the rats that had been controls but were now exposed to the experimental conditions intermittently during the subsequent 100 days also exhibited significantly more overt seizures [$F(1,98) = 7.32$, $p < .01$; eta = 0.28] when the magnetic fields were activated whereas the control rats (that had been previously exposed to the experimental condition) did not show this change [$F(1,98) = 0.92$, $p > .05$].

For part I, multiple regression analysis showed a statistically significant increase [$F(2,97) = 8.74$, $p < .001$] in overt seizures (MR = 0.37; adjusted r-squared = 12%] if the field had been activated during the night before (beta = 0.30) and the same (previous) night (beta = 0.24) as the food presentations. When all of the lags, between 0 and 3 for the occurrence of an A-index greater than or equal to 20 were allowed to enter the equation, only the value from two days before (lag 2) entered. The resulting multiple r value was increased to 0.42 [$F(3,108) = 7.90$, $p < .001$) and explained an additional 4% of the variability of the overt seizures. No variables entered the equation for the rats that did not receive the experimental magnetic fields. Verification of the additional contribution from ambient geomagnetic activity was shown when the residuals between the observed and the expected daily scores for overt seizures in the rats that received the experimental magnetic fields was predicted by the absolute A values (regression coefficient = 0.02) two days previously ($F(1,98) = 4.85$, $p < .05$; r-squared = 4%).

When multiple regression was completed with the additional variable for the presence of the power frequency fields (from the adjacent rooms), the multiple r value was 0.51

TABLE 1
Means (range 0 through 2) and standard deviations for scores of overt seizures for rats exposed to either the experimental magnetic fields or within the adjacent control area during periods of no presentation or presentation of the fields during part I and part II of the study.

	Experimental		Control	
	M	SD	M	SD
		Part I		
No Field	.25	.46	.10	.29
Field	.61	.50	.00	.00
		Part II		
No Field	.16	.37	.32	.53
Field	.46	.66	.21	.42
		Total Experiment		
No field	.21	.42	.19	.42
Field	.52	.59	.12	.33

[$F(4,95) = 9.29$, $p < .001$; adjusted r-squared = 23%]. When the power frequency variable was added to the regression analysis for the control group (that had been also inadvertently exposed to these fields through the wall), only this variable entered the equation and explained 12% of the variance [$F(1,98) = 17.14$, $p < .001$].

The results of multiple regression analysis for the second part of the experiment demonstrated that seizures increased significantly [$F(1,98) = 24.70$, $p < .001$; r-squared = 21%] if the field had been activated for two nights. None of the other lags for the experimental treatment for the occurrence of geomagnetic activity over an A value of 20 entered the equation. For the rats exposed to the reference environment, variables for the experimental fields did not enter the equation whereas the occurrence of A values greater than 20 one day before the observed seizures was significant statistically ($r = 0.20$; $p < .05$).

Subsequent analysis combined both parts of the experiments. One way analysis of variance as a function of the number of nights of exposure to the experimental conditions (0, 1 or 1 through 3) was statistically significant; *post hoc* analysis indicated that significantly more seizures were observed after two nights of exposures to the nocturnal magnetic field treatment than after only one night of exposure (see Fig. 1). Two way analysis of variance (all dfs = 1,28) for the numbers of seizures per day as a function of the two ripple frequencies (7 Hz, 45 Hz) and the two intensities (low, high) showed no statistically significant main effects or interactions. However it may be relevant that the higher probability of seizures following nights with the 7 Hz, less intense amplitudes (24 nT to 55 nT) relative to the stronger fields for this frequency and either of the 45 Hz conditions, approached statistical significance [$F = 3.48$, $0.05 > p > .10$].

DISCUSSION

The results of this study showed that experimentally generated magnetic fields whose temporal presentations and morphological features simulate brief, sudden storm commencements were associated with a significant increase in the display of overt seizures during synchronized feeding. This effect was not observed in rats that were exposed to the control (reference) environment (variations < 10 nT) but became evident, as a part of the counterbalanced design, when these rats were exposed to the fields. The presence of the experimental fields accommodated about 7% to 10% of the variance and was similar in magnitude to the effect size from the contribution of daily geomagnetic activity (7%) to these overt paroxysmal behaviours. This magnitude of effect size is also comparable to those observed for rats (Persinger, 1995a) and for humans beings (Rajaram & Mitra, 1981).

Although comparable effect sizes are a major indicator of the approximations by experimental treatments of natural phenomena, similarities in temporal profiles of the "critical stimuli" should also be present. The intermittent presentation of the experimental field or the activation of the geomagnetic field (over an A value of 20) were most powerfully (and significantly) associated with an increase in the incidence of seizures one or two days later. That the onset rather than the offset of the experimental fields increased the probability of overt seizures was indicated by the failure for a second increase in seizures to occur during the two days after the cessation of the fields.

The lag effect between the onset of experimental magnetic fields or the activation of the geomagnetic field and the occurrence of target behaviors has been shown for some studies but must be viewed cautiously. Other studies have shown a maximum association between

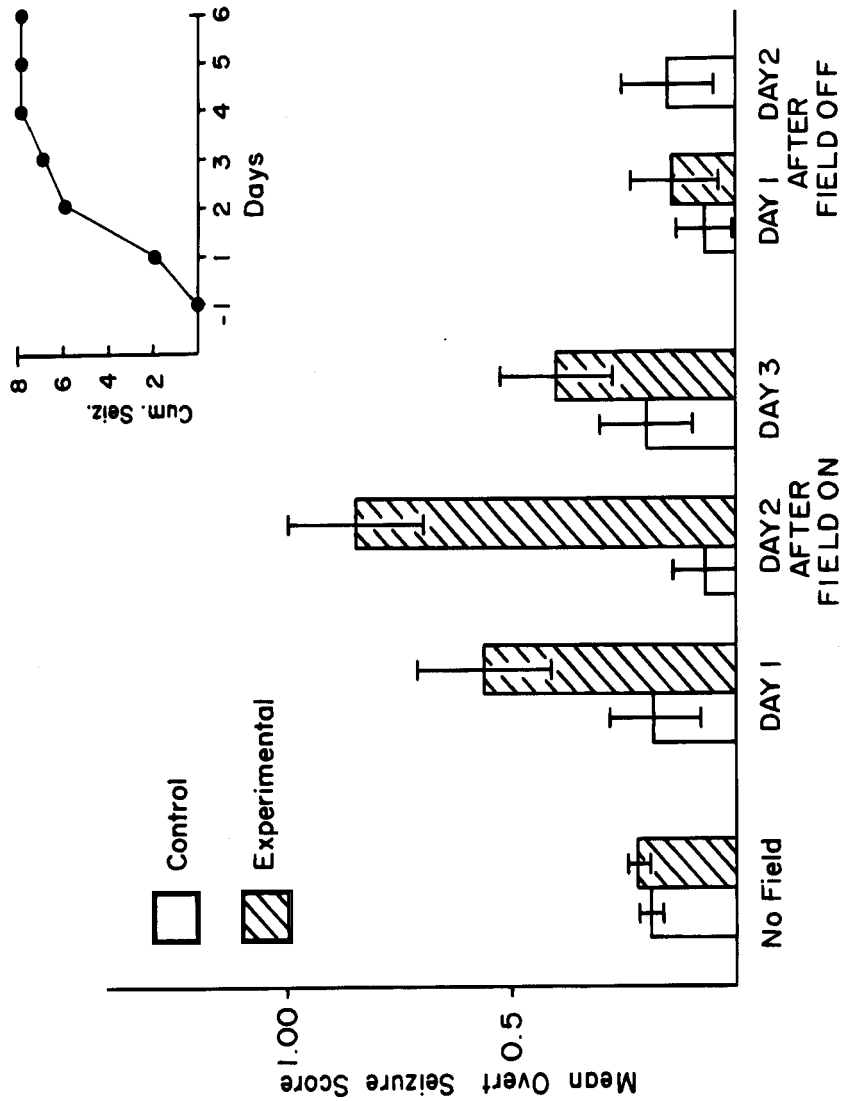

FIGURE 1 Means and standard errors of the mean for the overt seizure scores following nights during which there was no presentation of the experimental magnetic fields, after one, two or three nights of presentation, or after the first and second night of the termination of the field for exposed and non-exposed rats. Inset (upper right) indicates cumulative seizures during accidental exposure to 60 Hz magnetic fields generated from an adjacent room.

behaviors and the geomagnetic activity during the same 24 hr period (Persinger, 1988). One possible explanation could be related to the generally very quiet conditions of the geomagnetic field during the latter half of the year 1995. It is possible that very intense geomagnetic activity during the previous scotophase would have precipitated an increase in seizure incidence during the same day.

The observation that presentation of the experimental field continuously between midnight and 0800 hrs did not enhance the incidence of seizures significantly beyond the values for rats exposed for only 8 min, once per hour during the same 8-hr period indicates both sensitivity and saturability of the neurochemical systems that mediate the seizures. The effects of other electromagnetic stimuli, such as white light, upon melatonin for example have induced near-maximum effects after a brief (e.g, less than 5 min) exposure. Yaga *et. al.* (1993) employed a field (25 microT) whose polarity was shifted once per min for 60 min during the later scotophase and elicited an approximately 40% reduction in the activity of nocturnal NAT (n-acetyl transferase) and an approximately 20% reduction in levels of pineal melatonin.

The chronic, limbic epileptic rat may be a useful model for determining the mechanisms by which geomagnetic activity (or more likely a factor composed of geophysical and solar-interplanetary events that are correlated with the scalar values by which we infer changes in geomagnetic activity) affect the neuroelectrical processes. This experimenter's model has been that melatonin contributes to the inhibition of the electrical lability within the limbic system that is enhanced by the release of CRF which is encouraged by synchronized feeding (Persinger, 1995b). A sudden decrease in nocturnal melatonin levels, due to the direct effect of the key geomagnetic parameters upon the brain, would increase the epileptogenic impact of this neuropeptide when the conditioned stimulus (CS) is presented near the end of the photophase.

If these limbic epileptic rats also exhibit significantly and chronically elevated nocturnal melatonin levels to which the vulnerable limbic neurons had habituated (as our behavioral data suggest), then experimental or geomagnetic fields would produce a relatively greater depletion of this serotonin derivative and hence increased risk of overt seizures. Transient alteration in the normal circadian periodicity of spontaneous seizures by the application of magnetic fields (Sandyk, Anninos & Tsagas, 1991; Sandyk & Anninos, 1992) may have facilitated the detection of the overt displays.

There were three general observations from this study that may be relevant to understanding the mechanism by which geomagnetic activity affects brain function. The first was that the presentation of the experimental field for more than two successive nights was associated with less of an impact upon the incidence of spontaneous seizures; this has been noted for geomagnetic activity specifically (Persinger, 1995a, b) and for environmental events in general (Persinger, 1980) and may explain the discrepancies between laboratories and between studies if values for the dependent variables, e.g., melatonin or behavior indices, are averaged in larger temporal increments (weeks) or if time-series analysis is completed without regard to the quantitative values of the interstimulus or interstorm intervals.

The second observation was the chance measurement and notation that an unexpected experiment in an adjacent room generated magnetic fields (through the walls) into the exposure area and that the intensities were sufficient to alter the daily incidence of seizures. Finally, in those three instances where an experimental treatment occurred during a geomagnetic activation, there was no exacerbation of the incidence of seizures. All of these observations suggest that the neurochemical condition that is depleted by the

application of magnetic fields is quantal and once the system adapts to its depletion the geomagnetic or magnetic activity is no longer effective until these stimuli are removed and the neurochemical condition is restored. The results of the present data are compatible with the observation that the restoration period is within the order of about one week (Kato, Honma, Shigemitsu & Shiga, 1994).

REFERENCES

Bureau, Y. R. J. & Persinger, M. A. (1993). Extreme hypothermia induced by a synergism of acute limbic seizures, physical restraint, and acepromazine: implications for survival following brain injury. *Psychological Reports, 72,* 248–250.

Bureau, Y. R. J. & Persinger, M. A. (1995). Decreased incidence of limbic motor seizures following twenty pairings of subclinical lithium-pilocarpine injections and a putative opiate-releasing magnetic field. *Electro- and Magnetobiology, 14,* 1–6.

Campbell, W. H. (1967). Geomagnetic pulsations. In S. Matshushita & W. H. Campbell (eds.) *Physics of Geomagnetic Phenomena.* Academic: N.Y., pp. 821–909.

Jacobson, J. I. (1994). Pineal-hypothalamic tract mediation of picotesla magnetic fields in the treatment of neurological disorders. *Panminverva medicina, 36,* 201–205.

Kato, M., Honma, K., Shigemtisu, T. & Shiga, Y. (1994). Recovery of nocturnal melatonin concentration takes place within one week following cessation of 50 Hz circularly polarized magnetic field exposure for six weeks. *Bioelectromagnetics, 15,* 489–492.

Keshavan, M. S., Ganadhar, B. N., Gautam, R. U., Ajit, V. B. & Kapur, R. L. (1981). Convulsive threshold in humans and rats and magnetic field changes: observations during total solar eclipse. *Neuroscience Letters, 22,* 205–208.

Lerchl, A., Honaka, K. O. & Reiter, R. J. (1991). Pineal gland 'magnetosensitivity' to static magnetic fields is a consequence of induced electric currents (eddy current). *Journal of Pineal Research, 10,* 109–116.

Lerchl, A., Reiter, R. J., Howes, K. A., Nonaka, K. O. & Stokkan, K.-A. (1991). Evidence that extremely low frequency Ca++– cyclotron resonance depresses pineal melatonin synthesis in vitro. *Neuroscience Letters, 124,* 213–215.

Mayaud, P. N. (1975). Analysis of storm sudden commencements for the years 1868–1967. *Journal of Geophysical Research, 80,* 111–122.

Michon, A., Koren, S. A. & Persinger, M. A. (1996). Attempts to simulate the association between geomagnetic activity and spontaneous seizures in rats by experimentally generated magnetic fields. *Perceptual and Motor Skills, 82,* 619–626.

Persinger, M. A. (1980). *The weather matrix and human behavior.* N.Y.: Praeger.

Persinger, M. A. (1988). Increased geomagnetic activity and the occurrence of bereavement hallucinations: evidence for melatonin-mediated microseizuring of the temporal lobe? *Neuroscience Letters, 88,* 271–174.

Persinger, M. A. (1995). Sudden unexpected death in epileptics following sudden, intense increases in geomagnetic activity: prevalence of effect and potential mechanisms. *International Journal of Biometeorology, 38,* 180–187. (a)

Persinger, M. A. (1995). Geophysical variables and behavior: LXXIX. Overt limbic seizures are associated with concurrent and premidscotophase geomagnetic activity: synchronization by prenocturnal feeding. *Perceptual and Motor Skills, 81,* 83–93. (b)

Persinger, M. A., Bureau, Y. R. J., Kostakos, M., Peredery, O. & Falter, H. (1993). Behaviors of rats with insidious brain damage induced by seizures following single peripheral injections of lithium and pilocarpine. *Physiology and Behavior, 53,* 849–866.

Persinger, M. A. & Makarec, K. (1993). Complex partial epileptic signs as a continuum from normals to epileptics: normative data and clinical populations. *Journal of Clinical Psychology, 49,* 33–45.

Persinger, M. A. & Richards, P. M. (1995). Vestibular experiences during brief periods of partial sensory deprivation are enhanced when daily geomagnetic activity exceeds 15 to 20 nT. *Neuroscience Letters, 194,* 69–72.

Rajaram, M. & Mitra, S. (1981). Correlations between convulsive seizures and geomagnetic activity. *Neuroscience Letters, 24,* 187–191.

Richards, P. M., Persinger, M. A. & Koren, S. A. (1993). Modification of activation and evaluation properties of narratives by weak complex magnetic field patterns that simulate limbic burst firing. *International Journal of Neuroscience, 71,* 71–85.

Roberts, R. J., Gorman, L. L., Lee, G. P., Hines, M. E., Richardson, E. D., Riggle, T. A. & Varney, N. R. (1992). The phenomenology of multiple partial seizure-like symptoms without stereotyped spells: an epilepsy spectrum disorder? *Epilepsy Research, 13,* 167–177.

Sandyk, R. & Anninos, P. A. (1992). Magnetic fields alter the circadian periodicity of seizures. *International Journal of Neuroscience, 63,* 265–274.

Sandyk, R., Anninos, P. A. & Tsagas, N. (1991). Age-related disruption of circadian rhythms: possible relationship to memory impairment and implications for therapy with magnetic fields. *International Journal of Neuroscience, 59,* 259–262.

Silberstein, R. B. (1995). Neuromodulation of neocortical dynamics. In L. Nunez (ed.) *Neocortical dynamics and human EEG rhythms.* Oxford: N.Y., pp. 591–627.

Yaga, K., Reiter, R. J., Manchester, L. C., Nieves, H., Sun, J.-H. & Chen, L-D. (1993). Pineal sensitivity to pulsed static magnetic fields changes during the photoperiod. *Brain Research Bulletin, 30,* 153–156.

Zeise, M. L. & Semm, P. (1988). Melatonin lowers excitability of guinea pig hippocampal neurons in vitro. *Journal of Comparative Physiology, 157,* 23–29.